AN ANNOTATED BIBLIOGRAPHY OF RED TIDES OCCURRING IN THE MARINE WATERS OF FLORIDA

Robert F. Hutton
Florida State Board of Conservation Marine Laboratory
St. Petersburg, Florida

'Red Tide' is a popular name given to discolored waters caused by the aggregation or tremendous increase (blooming) of microscopic organisms. This name was evidently coined for the phenomenon occurring along the west coast of Florida wherein a species of dinoflagellate, *Gymnodinium brevis* Davis, periodically 'bloomed', discolored the water, and resulted in 'fish kills'. The term has been in widespread use for the past eight years and it is now used for nearly all biological phenomena resulting in the discoloration of waters even if 'fish kills' do not occur.

Among the micro-organisms responsible for 'blooms' are bacteria, diatoms, algae, flagellates, ciliates, chaetognaths, and certain crustacea. These 'blooms' occur all over the world in both fresh water and in salt water, and the discoloration caused may acquire brown, yellow, greenish-yellow, green, blue-green, amber, red, or other hues. A variety of terms has been given to discolored waters including 'red water', 'bloody water', 'red plague', 'yellow water', 'stagnant water', 'rotten water', and 'poisoned water'.

Gymnodinium brevis, an unarmored dinoflagellate, has been incriminated by its association with Red Tides in lower Florida west coast waters. In a number of cases since 1946 'blooms' of *G. brevis* have been associated with catastrophic mass mortality of marine organisms. Ray (personal communication) has grown *G. brevis* in bacteria-free cultures and using these cultures he has killed fishes experimentally in aquaria where the bacterial count remained low. Howell (1951) identified *Gonyaulax monilata* sp. nov., an armored dinoflagellate, as the causative agent of a Red Tide on the east coast of Florida during August-September, 1951. A minor fish-kill was associated with this Red Tide. Bein (1954) described *Flavobacterium piscicida* sp. nov., a chromogenic bacterium, from a fish-kill in Florida waters in which a dinoflagel-

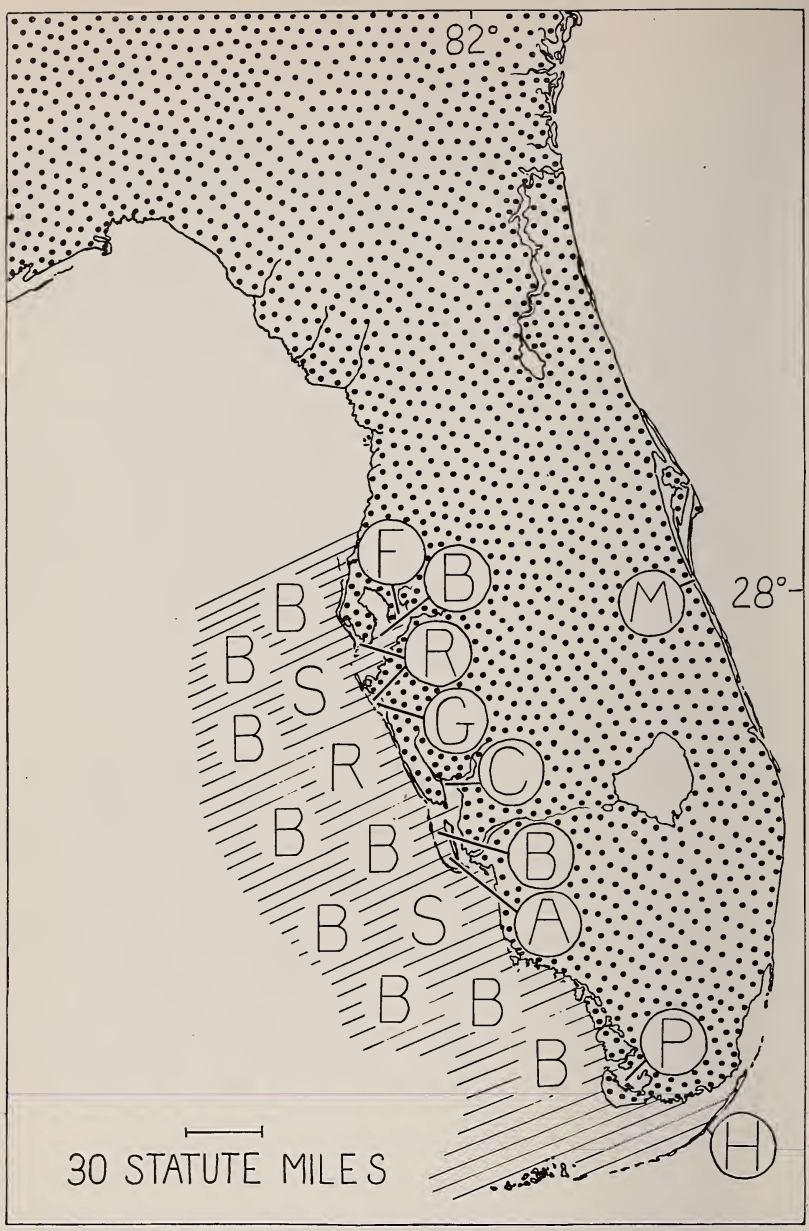

Figure 1. Map showing 'Red Tide' occurrences in the coastal waters of southern Florida.

LEGEND

A — *Acartia* sp.
B — *Gymnodinium brevis* Davis
C — *Coscinodiscus* sp.
F — *Ceratium furca* (Ehrenberg)
G — *Gonyaulax* sp.
H — *Rhizosolenia* spp.
M — *Gonyaulax monilata* Howell
P — *Flavobacterium piscicida* Bein
R — Purple Water caused by bacteria
S — *Skujaella* sp.

late bloom was not present. At Ballast Point in Hillsborough Bay south of Tampa, Florida, a minor Red Tide occurred periodically during 1955. Fishes did not seem to be harmed as minnows *(Gambusia)* and mullet *(Mugil)* were seen swimming through the streaked areas from time to time. However, shrimp in bait-wells located on the fishing pier at Ballast Point died when this water was pumped into the wells although good water circulation was maintained. A dinoflagellate, *Ceratium furca* (Ehrenberg), was the predominate organism in the waters examined and counts as high as 17,600,000 cells per liter were observed.

In addition to the dinoflagellates *Gymnodinium brevis* and *Ceratium furca,* the author has observed other blooms along the west coast of Florida. An unidentified species of *Gonyaulax* was observed on several occasions in water samples from Sarasota Bay near Longboat Key. Blooms of a chromogenic bacterium causing 'purple water' were observed near shore at a number of places along Florida's west coast. In one case water with a peculiar greenish-yellow color was found to contain large numbers of a species of *Acartia. Skujaella* sp., an alga belonging to the Myxophyceae, commonly blooms in the marine waters of the lower Florida west coast. During the months of June through August, *Rhizosolenia* spp. has been observed in bloom proportions along the lower east coast of Florida by the author. These blooms discolored the water but did not appear to be harmful to other marine life. Lackey (1955) reported a bloom of the diatom *Coscinodiscus* in the area around the mouth of the Myakka River in 1953.

Hayes and Austin (1951) have stated that discolored waters frequently resemble shoals. For this reason the knowledge of where discolored waters occur and the causative agents of these waters is important to the navigator.

The author is indebted to Mrs. Bonnie Eldred for preparing the map shown in Figure 1, and to Mr. Robert M. Ingle for reading the paper in manuscript and offering valuable comments.

AGASSIZ, ALEXANDER. 1890. The topography of Florida. By N. S. Shaler. With a note by Alexander Agassiz. *Bull. Mus. Comp. Zool. Harv., 16*(7): 139-158.

p. 158. ". . . To the damming up of the waters in the Everglades, and to the sudden outbursts of gigantic masses of water charged with organic matter and lime, we may trace the immense destruction of fishes which so frequently occurs on the shores of the Florida keys and the waters surrounding them."

ANONYMOUS. 1881. Mortality of fish in the Gulf of Mexico. *Ann. Mag. Nat. Hist.*, Ser. 5, *8:* 238-240.

This article contains excerpts of a letter by M. A. Moore, writing on November 30, 1880, from Braidentown, Manatee County, Florida, to Prof. S. F. Baird. Moore reports fish being killed by poisoned water. He states that the poisoned waters seemed to be more localized around the mouth of Charlotte Harbor and off Punta Rassa than elsewhere. Bottom fish seemed to be more commonly affected. He believes that water conditions are caused by some sort of volcanic action at the bottom. Also, this article contains a summary of the work which is reported by Endlich (1882).

ANONYMOUS. 1883. Poisoned water in the Gulf of Mexico. *Bull. U. S. Fish Comm., 2:* 104. (From the Sunland Tribune, Tampa, July 20, 1882.)

"We learn from Capt. William Jackson, of the steamer 'Lizzie Henderson', that on his trip from Cedar Key, Tuesday, he encountered a streak of poisoned water, covered with all varieties of dead fish, of more than a mile in extent, off Indian Pass, between Clear Water and Egmont Light. The captain says that a very offensive smell arose from it, and that a good many bottom fish, such as eels, were floating dead on the surface. We opine that this fact upsets the theory of some as to this poisoned water being fresh water from overflow on the mainland, impregnated with poisoned vegetable matter, as there are no streams of any size flowing into the Gulf near where these fish were found."

ANONYMOUS. 1885. Report of the commissioner. *Rep. U. S. Comm. Fish.*, Part II: 68-69.

The probable reason for the rapidly diminishing fisheries in the Gulf of Mexico are given.

p. 69. ". . . probably partly overfishing in particular localities, and partly the numerous pestilences and mortalities by which so many are exterminated. No satisfactory theory has been presented for this mortality, although an intelligent writer suggests that it is due to the influx of the cold water found near the sea bottom at great depth even in the Gulf Stream, which has the same effect as the northers on the coast of Texas during the winter-time."

ANONYMOUS. 1947. Red tide and fish mortality on the Florida west coast. *Marine Laboratory, University of Miami,* Spec. Serv. Bull. No. 1: 1-9. (Mimeographed)

A preliminary discussion of the red tide problem in Florida waters.

ANONYMOUS. 1953. Factors in "red tide" outbreak of 1952. *Progr. Fish Cult., 15*(3): 128.

"While processing data collected during the November 1952 outbreak of 'red tide' off the coast of Florida, the Gulf Fishery Investigations of the U. S. Fish and Wildlife Service found good evidence that effluents of the Caloosahatchee River are important agents in such blooms. It has been noted that activity of this type is probably due to organic content as well as to physical attributes. Experimental work in tanks has indicated that high light intensity, vitamin B_{12}, and sulfides are some of the requirements for mass growth of dinoflagellates as well as other organisms.

"Chemical analyses that have been made by the Geochemistry and Petrology Branch, U. S. Geological Survey, show that significant quantities of titanium and zirconium were present in the 'red tide' bloom water—and not in other waters such as Lake Okeechobee, the surface of Sigsbee Deep, and the tidal lagoon at Galveston."

ANONYMOUS. 1955. Red tide bacteria studies. *Sth. Fisherman, 15*(1): 16 & 58.

A popular account of the bacterial studies being carried out in connection with Florida's red tides.

BAUGHMAN, J. L. 1947. *An Annotated Bibliography of Oysters with Pertinent Material on Mussels and other Shellfish and an Appendix on Pollution.* Tex. A & M Research Foundation, 794 pp.

This work contains a number of references on the red tides of Florida.

BEIN, SELWYN JACK. 1954. A study of certain chromogenic bacteria isolated from "red tide" water with a description of a new species. *Bull. Mar. Sci. Gulf and Caribbean, 4(2):* 110-119.

"ABSTRACT. Experiments performed with a chromogenic bacterium designated as *Flavobacterium piscicida* (sp. nov.) indicates that this organism in pure culture is capable of killing certain fishes under laboratory conditions. This organism was isolated from a fish kill in which no dinoflagellate bloom was present. Similar bacteria have been isolated from Red Tide outbreaks attributed to *Gymnodinium brevis* and from *G. brevis* cultures at the Marine Laboratory and indicates the possibility that a bacterium may be associated with fish deaths under natural conditions. Further investigation is warranted as to the possible relationship of bacteria and dinoflagellates in causing the phenomenon known as 'Red Tide'."

BEIN, SELWYN JACK. 1955. Red tide bacterial studies. *Marine Laboratory, University of Miami,* Special Service Bulletin No. 10. Pp. 1-2. (Mimeographed)

p. 2. "The conclusions drawn from these experiments are as follows: The fish are killed by a water soluble, toxic material, *produced by the growth of the bacteria.* The toxin is thermolabile, that is, unstable at high temperatures, but extremely poisonous under natural climatic conditions. Given the correct conditions these organisms appear capable of 'blooming' and causing mass mortality of marine organisms in nature."

BRICE, JOHN J. 1898. 6.-The fish and fiisheries of the coastal waters of Florida. *Rep. U. S. Comm. Fish.,* Part 22: 263-342.

One theory as to the cause of sponge deaths is that poisonous waters come out of some of the Florida west coast rivers and kills them.

BRONGERSMA-SANDERS, MARGARETHA. 1948. The importance of upwelling water to vertebrate paleontology and oil geology. *Kon. Ned. Ak. Wet., Verh. Afd. Nat.* (Tweede Sectie), *45*(4): 1-112.

This work contains a section dealing with mortality of marine animals along the coast of Florida.

CARLSON, Y. A. 1908. Brilliant Gulf waters. *Monthly Weather Review, 36:* 371-372.

Streaks of brilliantly-hued (luminescent) waters were encountered in the Gulf of Mexico. No mention of "red" water or fish-kills was made.

CHEW, FRANK. 1953. Results of hydrographic and chemical investigations in the region of the "red tide" bloom on the west coast of Florida in November 1952. *Bull. Mar. Sci. Gulf and Caribbean,* 2(4): 610-625.

"ABSTRACT. Eleven hydrographic stations were occupied in the *Gymnodinium* bloom area off Fort Myers, Florida, in November 1952. These data provide the basis for a three-dimensional description of the hydrographic environment where the phenomenon occurred.

"The current pattern in the area of study was more complex than is generally thought. There was eddying motion which appears to be seasonal in character.

"Regions of maximum total phosphorus were found to coincide with water of Gulf origin, while water with greater river influence contained regions of minimum total phosphorus. This pattern implies that the increased phosphorus content probably came from the open Gulf.

"The total phosphorus changed slowly with depth in a slanting water column, and areas of definite *Gymnodinium* bloom, while high in total phosphorus, did not coincide with areas of maximum observed total phosphorus which was some ten times the normal value.

"Three mechanisms capable of effecting the observed total phosphorus pattern are given. No proven explanation of the causes of the recurrent plankton blooms is as yet available."

CHEW, FRANK. 1955. On the offshore circulation and a convergence mechanism in the red tide region off the west coast of Florida, *Marine Laboratory, University of Miami* (Report to Florida State Board of Conservation). Pp. 1-26. (Mimeographed)

"ABSTRACT. The offshore water is shown to move as a single column. The sloping bottom and the equation of continuity are then applied to show the existence of a horizontal convergence mechanism which, over a period of several weeks, may effect an increase in concentration of floating particles some several times its initial value. The southbound current in the 'loop' is thought of as a Rossby jet which drives the cyclonic eddy offshore. Consideration of the abbreviated verticity equation, together with the fact of sloping bottom, show that the southeastern quadrant of the cyclonic eddy possesses increasing negative vorticity and hence the organisms previously concentrated will tend to wash ashore. Some consideration of the effects of wind are also included."

CHEW, FRANK. 1955. The summer circulation of the Florida west coast offshore water as deduced from the pattern of thermocline depths and a nongeostrophic equation of motion. *Marine Laboratory, University of Miami* (Report to Florida State Board of Conservation). Pp. 1-6. (Mimeographed) Also: *Trans. Amer. Geophysics Union, 36*(6): 963-974.

"ABSTRACT. On the basis of the pattern of thermocline depths as read from Bathythermograms and a non-geostrophic but steady state equation of motion, the circulation of the water off the Florida west coast is deduced. This circulation agrees with that found previously on the basis of horizontal salinity patterns. Since salinity and Bathythermograph measurements were made by independent tools, the agreement is significant."

CHEW, FRANK. 1955. Red tide and the fluctuation of conservative concentrations at an estuarine mouth. *Bull. Mar. Sci. Gulf and Caribbean, 5*(4): 321-330.

"ABSTRACT. A set of observations of the conservative concentration, salinity, at an estuary mouth in a Red Tide region is generalized by an extension of the mixing length theory of tidal flushing for steady state to one for transient state. The river flow and tidal current are taken as functions of time, but not of space. The solution confirms the expectation that the intensity of the zone of rapid transition of conservative concentrations is greatest during high river flow and low tidal ranges. The solution also indicates that the tidal advection and diffusion reinforce each other."

COLLIER, ALBERT. 1953. Titanium and zirconium in bloom of *Gymnodinium brevis* Davis. *Science, 118*(3064): 329.

"As a result of the analysis, it was found that titanium was peculiar to the red-tide water at a concentration of 0.01-0.1% of total solids (33,700 ppm), and zirconium at 0.001-0.01% total solids (33,700 ppm). These elements did not appear in the other samples.

"The largest contributor to the nonoceanic component of the neritic waters of the Sanibel Island region is Lake Okeechobee and the analysis of this water showed the presence of Ca, Na, Mg, Si, Sr, K, Al, Sn, Fe, Ba, Ni, B, Pb, Cu, Mn, Cr, and Ag, but not Ti and Zr. It is likely that Ti and Zr are normally present in the sea water in traces beyond the sensitivity of the analytical method, but in this case were concentrated by the organisms of the mass bloom. The standard sensitivities given for the spectrographic

method (semi-quantitative) are for zirconium 0.001%, and for titanium 0.001%.

"These elements will be studied as nutritional trace elements in the cultural studies of dinoflagellates now in progress in this laboratory."

COLLIER, ALBERT. 1953. The significance of organic compounds in sea water. *Trans. 18th N. Amer. Wildl. Conf.*, pp. 463-472.

"SUMMARY. That sea water contains a significant quantity of dissolved organic compounds is a long recognized fact. More recently, biological differences between waters have been proven and their effects on the survival of invertebrate larvae demonstrated. It has been shown that substances which may originate in the photosynthetic process have a direct and quantitative influence on the feeding rate of oysters.

"In the laboratories of the Gulf Fishery Investigations of the U. S. Fish and Wildlife Service carbohydrate and proteinaceous substances are being isolated and purified for experimental testing on living organisms, including young fish and dinoflagellates.

"The principal fields of possible significance of these compounds are: as an energy source; as regulators or stimulators of feeding activities; effects on movements of marine animals; toxins; and in the evaluation of the biological activity within discrete bodies of water."

COLLIER, ALBERT. 1955. Newsletter on red tide research. *U. S. Fish and Wildl. Serv.* (April). Pp. 1-2. (Mimeographed)

A small bloom of *Gymnodinium brevis* was created in the laboratory. At concentrations of 3,000,000 individuals per liter cultures of this organism were used to kill fish experimentally. It was reported that bacteria-free cultures of *G. brevis* were being maintained in the laboratory.

COLLIER, ALBERT W., and KENNETH T. MARVIN. 1953. Stabilization of the phosphate ratio of sea water by freezing. *Fish. Bull., U. S., 54*(79): 71-76.

This reference has been included since phosphorus has been suggested as being a possible limiting factor in the case of Red Tide blooms.

COLLINS, J. W. 1887. XIV.-Report on the discovery and investigation of fishing-grounds, made by the Fish Commission Steamer 'Albatross' during a cruise along the Atlantic coast and in the Gulf of Mexico; with notes on the Gulf fisheries. *Rep. U. S. Comm. Fish.*, Part 13: 217-311.

This report mentions 'poisoned water' along the Florida coast. The water was said to seriously affect marine life, including sponges. Ingersoll (1882) is cited. According to Collins (p. 249): "Mr. Silas Stearns, who has had exceptional opportunities for becoming familiar with the subject which Mr. Ingersoll refers to, is authority for stating that the sponge fishery about Anclote Keys was not to any appreciable extent injuriously affected by the poisonous water. He was there in 1878, 1879, and 1880: part of the time employed as an expert by the United States Government to investigate the fisheries of western Florida and collect statistics of them for the Tenth Census. On one occasion he took a boat-load of sponges himself near Anclote, in 2 fathoms of water, a feat that pretty effectually settled the question as to whether the sponges were all destroyed in this region."

CORNMAN, IVOR. 1947. Retardation of *Arbacia* egg cleavage by dinoflagellate-contaminated sea water (red tide). *Biol. Bull., Woods Hole, 93*(2): 205.

"ABSTRACT. Two specimens of 'red tide' were generously supplied by Dr. P. S. Galtsoff, Director of the U. S. Fisheries Laboratory, Woods Hole, Massachusetts.

"An untreated decomposing sample of sea water taken from an area stained red by *Gymnodinium* when diluted 1:10 retarded *Arbacia*

egg cleavage by one hour—100 percent increase in cleavage time—if added 10 minutes after fertilization. When most of the H_2S was pulled off with a vacuum pump, the delay at 1:10 was only 3 minutes and at 1:5 was 15 minutes. Four days later all odor of H_2S was gone, but retardation was essentially the same, 9 percent at 1:10 and 27 percent at 1:5. Cytolysis resulted from exposure to 1:2. This inhibitory potency is equal to that of crude filtrate from some *Penicillium* cultures. This sea water sample killed *Fundulus* in 2 hours at 1:2 and in 5½ hours at 1:10. A 'red tide' plankton sample suspended in sea water and preserved with $CHCl_3$ was evacuated until no odor of $CHCl_3$ remained. At 1:10 this retarded cleavage 10 minutes. *Fundulus* in this sample diluted with an equal part of sea water lost equilibrium and became sluggish in 2 hours, and in 6 hours at 1:10. They recovered motility in fresh sea water, but subsequently died. There appears to be some parallel between the toxicity to fish and to dividing eggs, but whether the same poison acts upon both and whether decomposition plays an important role remain to be determined. Studies conducted near the site with fresh samples of sea water and dinoflagellates should prove more helpful if uncontaiminated test organisms are available."

DAVIS, CHARLES C. 1948. *Gymnodinium brevis* sp. nov., a cause of discolored water and animal mortality in the Gulf of Mexico. *Bot. Gaz., 109*(3): 358-360.

Along the lower Florida west coast in 1947, a species of the genus *Gymnodinium* was found associated with a yellowish-green discoloration of water and mortality of marine animals. This dinoflagellate was enormously abundant, occuring in numbers as high as 60,000,000 per liter. This organism appeared to be new to science. It was described under the name *Gymnodinium brevis.*

DAVIS, CHARLES C. 1949(1950). Observations of plankton taken in marine waters of Florida in 1947 and 1948. *Quart. J. Fla. Acad. Sci., 12*(2): 67-103.

Dinoflagellates were shown to dominate the plankton of certain samples taken during a period of Red Tide.

DELANY, M. 1956. Cultivation of a presumably autotrophic dinoflagellate. *Amer. Midl. Nat. (in press)*

EMERSON, D. L. 1948. Preliminary survery on the Florida red tide phenomenon. *Marine Laboratory, University of Miami.* Pp. 1-2. (Mimeographed)

Red tide is said to have occurred along the west coast of Florida in 1844; 1854; 1878; 1880; 1882; 1908; 1916; from November, 1946, to March, 1947; and in July and August, 1947. 'Plankton blooming' is discussed; it is stated that 'blooming' does not always cause mortality of marine animals.

P. 2. "Various hypotheses have been advanced to account for the red tide phenomena. Some early observers believed the disaster to be due to an underwater eruption of poisonous springs released by earthquakes, to the leaching of poisonous substances by streams, and in the past occurrence to the dumping of poisonous gases, chemicals, and other war munitions into the Gulf as a method of disposal. These appear to be groundless suppositions and have since been disregarded."

A program for work on red tide is suggested.

ENDLICH, F. M. 1882. An analysis of water destructive to fish in the Gulf of Mexico. *Proc. U. S. Nat. Mus., 4:* 124.

A report in the form of a letter on the analysis of two samples of Gulf water, (A) in which fish die, and (B) normal, or good water.

The author's findings were:

	A.		B.
"Specific gravity	1.024		1.022
Solid constituents (total), percent	4.0780		4.1095
Ferric compounds, percent	0.1106		0.0724
Injurious organic matter ratio	= 3	=	2"

Also: "In my estimation the death of fish was caused by the more or less parasitic algae, which was found in large quantities in water A, but do not occur at all in water B."

FARLOW, W. G., Dr. 1882. Report on the contents of two bottles of water from the Gulf of Mexico, forwarded by the Smithsonian Institution. *Proc. U. S. Nat Mus., 4*: 234.

The contents of the bottles were alike and the major portion of the contents was "a mass of amorphous slime". Evidently a preservative was not used in either bottle.

FIENSTEIN, ANITA, A. RUSSELL CEURVELS, ROBERT F. HUTTON and EDWARD SNOEK. 1955. Red tide outbreaks off the Florida west coast. *Marine Laboratory, University of Miami* (Report to the Florida State Board of Conservation). Pp. 1-44. (Mineographed)

"ABSTRACT. A compilation of reports of Red Tide on the west coast of Florida from 1844 to January, 1955, is given. Also included are two working diagrams of incidence of Red Tide, suggesting that (1) Red Tide occurs more frequently in the months August through January, (2) the individual Red Tide outbreaks are part of larger outbreaks which seem to move from south to north, and (3) summer outbreaks appear to originate mostly north of Venice, winter and spring outbreaks farther south. Further data are required to give complete support to (2). If this is substantiated, it is pointed out that control may be exerted by action in a limited focal area or areas of origin. Otherwise the problem of control may be of the greatest difficulty since it will require action over a much wider area or areas."

FISH, CHARLES J., and MARY CURTIS COBB. 1954. Noxious marine animals of the central and western Pacific Ocean. *U. S. Fish and Wildl. Serv.*, Research Report 36: 1-45.

This work contains a number of references on toxic plankton including some on Florida's red tide problem.

FLORIDA STATE BOARD OF CONSERVATION. 1949. Eighth Biennial Report (1947-48). Pp. 1-39.

The red tide outbreaks of 1946-47 and the scientific research carried out on these outbreaks are discussed.

FLORIDA STATE BOARD OF CONSERVATION. 1950. Ninth Biennial Report (1949-50). Pp. 1-61.

A brief mention of Florida red tide research is made.

FLORIDA STATE BOARD OF CONSERVATION. 1953. Tenth Biennial Report (1951-52). Pp. 1-66.

p. 49. "Several investigations were made of fish deaths due to pollution, notably in the Miami River and at Ft. Lauderdale. Reduced oxygen content of the water was found to be responsible in all cases.

"Late in 1952 an outbreak of Red Tide occured on the Florida West Coast. A team of biologists and hydrographers gathered data on this, employing an airplane and a chartered vessel which was equipped with portable oceanographic equipment. A series of hydrographic stations was made across two principal areas of the outbreak. The organism was found to be the same as the one responsible for the serious Red Tide of 1947,

Gymnodinium brevis. Cultures of the organism have been established and are growing in the laboratory.

"The 1952 outbreak was not as serious as that of 1947, but at the time that this report was prepared (January 1953), Red Tide was still present.

"Analysis of the data collected will attempt to correlate hydrographic conditions with the blooms of the Red Tide organism, to increase our understanding of this serious phenomenon."

FLORIDA STATE BOARD OF CONSERVATION. 1955. Eleventh Biennial Report (1953-54). Pp. 1-43.

A review of the scientific research being carried out in Florida waters is included.

GALTSOFF, PAUL S. 1948. Red tide. Progress on the investigations of the cause of mortality of fish along the west coast of Florida conducted by the Fish and Wildlife Service and cooperating organizations. *Spec. Sci. Rep. U. S. Fish Wildl. Serv.*, (46): 1-44.

The literature on the blooming of aquatic micro-organisms is reviewed briefly. The Florida red tide is discussed and the characteristics and effects of red water are reported. The color of the water in which fish had died was reported as green, greenish yellow, yellow, amber, brown, reddish, and red. One of the predominant organisms was *Gymnodinium* which varied from 13,000,000 to 56,000,000 per liter. The total phosphorus was "from 5 to 10 times as high as those ever encountered in uncontaminated oceanic water." An odorless, irritating gas, associated with onshore winds and breaking of the surf, was described. "It caused spasmic coughing, a burning sensation in the throat and nostrils, and irritation of the eyes." Control measures are discussed, but "no definite recommendation for control can be made at present." Economic losses are mentioned and conclusions are stated.

GALTSOFF, PAUL S. 1949. The mystery of the red tide. *Sci. Mon., N. Y.*, 58(2): 109-117.

Contains essentially the same information as Galtsoff (1948).

GEYER, RICHARD A. 1950. A bibliography on the Gulf of Mexico. *Tex. J. Sci.*, 2(1): 44-93.

In Appendix A and Appendix B this work includes references on mass mortality of aquatic organisms in various parts of the world.

GILL, THEODORE. 1883. Zoology. *Ann. Rep. Board of Regents of the Smithsonian Inst., showing the operations, expenditures and condition of the Inst. for the year 1881:* 465-467.

A report on "fish epidemics" in the Gulf of Mexico, including a list of references published in the *Proc. U. S. Nat. Mus.*

GLAZIER, W. C. W. 1882. On the destruction of fish by polluted waters in the Gulf of Mexico. *Proc. U. S. Nat. Mus., 4:* 126-127.

A report of colored water in which fish died during about 1865 and in 1878 and 1880. The 1880 mortality occurred in the waters of Tampa, Sarasota, and Charlotte Harbor.

GLENNAN, A. H. 1887. 4.-Fish killed by piosonous water. *Bull. U. S. Fish Comm., 6:* 10-11.

A report of fish killed by 'poisoned water' of a reddish color during October, 1885. Large shoals of dead fish were reported between Egmont Key Light and Charlotte Harbor. Also reported was "that in some of the freshwater creeks fish are caught by placing bags of the bruised bark of the swamp dogwood (*Cornus sericea*) in still water, and that the fish will revive if allowed to remain in it for a short time only." (p. 11)

GRAHAM, HERBERT W. 1954. Dinoflagellates of the Gulf of Mexico. In "Gulf of Mexico. Its origin, water, and marine life." *Fishery Bulletin of the U. S. Fish and Wildlife Service*, 55(89): 223-226.

The dinoflagellate plankton along the west coast of Florida is mentioned in connection with the red tide.

GRAHAM, HERBERT W., JOHN M. AMISON and KENNETH T. MARVIN. 1954. Phosphorus content of waters along the west coast of Florida. *Spec. Sci. Rep. U. S. Fish Wildl. Serv.*, (122): 1-43.

"ABSTRACT. The distribution of inorganic and total phosphorus in the waters along the west coast of Florida is reported for a period of more than 16 months. Some upwelling to subsurface levels is evident but no hydrographic feature occurs which could account for the high values of phosphorus found during the 'red tide' of 1946-47. There is no evidence that either leaching from the bottom of the Gulf or outflow from local rivers contributes large quantities of phosphorus to the Gulf waters. However, values of total phosphorus comparable to those of the red tide were found in blooms of *Trichodesmium* floating on the surface over water of very low phosphorus content."

GUNTER, GORDON. 1947. Catastrophism in the sea and its paleontological significance, with special reference to the Gulf of Mexico. *Amer. J. Sci. 245*(11): 669-676.

"ABSTRACT. The importance of catastrophism and mass mortality in paleontology has been emphasized by certain recent writers. On the Gulf Coast of the United States mass mortalities of marine animals of shallow water, catastrophic in nature, are brought about every ten years or so by hard cold spells, plankton blooms, and excessively high salinities; the latter case being confined to the Laguna Madre of Texas. The vastness of the mortality, which may cover several hundred square miles, low temperatures, high salinity and silting due to high winds or heavy drainage from land, which may accompany the mortalities in various combinations, are conditions prejudicial to fossilization. Such events may occur thousands of times in a million years. Catastrophic mass mortalities of marine animals in the Gulf of Mexico are important factors in fossilization of the fauna of that region."

GUNTER, GORDON. 1949. The "red tide" and the Florida fisheries. *Proc. Gulf and Caribbean Fish. Inst.*, Inaugural Session: 31-32.

A review of Florida's red tide problem.

GUNTER, GORDON, F. G. WALTON SMITH, and ROBERT H. WILLIAMS. 1947. Mass mortality of marine animals on the lower west coast of Florida, November 1946 - January 1947. *Science, 105*(2723): 256-257.

During November, 1946, dead and dying fish and turtles were observed in the marine waters 10-14 miles offshore from Naples. By January 10, 1947, the mortality had reached northward to Boca Grande and fish were still dying in the bays behind Captiva and Sanibel Islands on January 29. The critical area for this mortality was from Dry Tortugas to Boca Grande. It was estimated that over 50,000,000 fish were killed in the area. All kinds of fish, oysters, clams, crabs, shrimp, barnacles and coquinas were killed. A species of *Gymnodinium* was observed in some of the waters. Salinities were observed to be normal, temperatures ranged from 22.5° C. to 26° C., pH was around 8.2, and dissolved oxygen, with one exception, was not low. Although hydrogen sulfide was reported earlier at Naples the writers could not detect any during their investigation. An odorless irritant 'gas' was reported on the Gulf Beach of Captiva Island from January 22 to 26.

GUNTER, GORDON, ROBERT H. WILLIAMS, CHARLES C. DAVIS, and F. G. WALTON SMITH. 1948. Catastrophic mass mortality of marine animals and coincident phytoplankton bloom on the west coast of Florida, November 1946 to August 1947. *Ecol. Monogr. 18*(3): 309-324.

"SUMMARY. 1. A mortality of marine fishes and other animals of catastrophic proportions took place along the lower West Florida coast between November, 1946, and August, 1947.

"2. In isolated places, and not in regular association with dying fish, low oxygen tension was found. This may have been associated with the decay of large numbers of dead animals and is to be considered a result rather than a cause of the mortality. The chemistry of the sea water was not found to be abnormal.

"3. The mass death of marine organisms was associated with the flowering of dinoflagellate, *Gymnodinium brevis.* Water that contained this organism killed fishes in an aerated aquarium and fishes were found dying in its presence in the sea, although the oxygen content was high. In some places *Gymnodinium brevis* reproduced so abundantly that patches of the water became saffron yellow in color and noticeably viscous. Schools of fishes entering this water died immediately. It is concluded that *Gymnodinium brevis,* like certain related dinoflagellates, is specifically poisonous to marine animals when present in large numbers.

"4. The weather was abnormally warm and still and a hurricane wind blew offshore on the lower Florida Gulf Coast during the fall of 1946. It is suggested that changed meteorological conditions or other factors may have brought about changes of the water masses which increased the supplies of nutrient salts and led to a flowering of the plankton, especially *Gymnodinium brevis.* The more remote possibility of seismic disturbances is also considered together with the possibility of causative factors other than an increase of nutrient salts.

"5. Records of similar catastrophic mortalities localized along the lower West Coast go back to 1844, and it is suggested that these instances had similar causes.

"6. Fishes found dead along the beaches show that the families of fishes of greatest abundance in lower Florida are quite different from those of the northern Gulf Coast and a transition from a temperate to a tropical fauna is indicated."

HAYES, HELAN LANDAU, and THOMAS S. AUSTIN. 1951. The distribution of discolored sea water. *Tex. J. Sci., 3*(4): 530-541.

This work contains a number of references on the red tides of Florida.

HELA, ILMO. 1955. Ecological observations on a locally limited red tide bloom. *Bull. Mar. Sci. Gulf and Caribbean, 5*(4): 269-291.

"ABSTRACT. In order to study the assumed importance of the passes in generating Red Tide outbreaks, the hydrographical tidal conditions were studied in the Boca Grande Pass. The results confirmed previous ones and indicated the two-layer character of this estuary. In the deeper water no *Gymnodinium brevis* was found. The heavier concentration was observed during all tidal phases on the side of Gasparilla Island, suggesting that they must have originated somewhere 'behind Gasparilla Island' and not in the area of the highest total phosphorus. As a second, simultaneous part of the study, an effort was made to find the areas from which the *G. brevis* in this case originated. In two separate spots (Stations 12 and 20) actual, locally limited Red Tide kills were observed. An optimum salinity for the *G. brevis* appeared to exist between 32 and 33 parts per thousand. A diurnal vertical migration of *G. brevis* was observed."

HELA, ILMO. 1956. A pattern of coastal circulation inferred from synoptic salinity data. *Bull. Mar. Sci. Gulf and Caribbean, 6*(1): 74-83.

"ABSTRACT. A synoptic operation was performed during the forenoon and noon hours on December 4, 1954 when 28 vessels occupied 230 limited hydrographic stations off the west coast of Florida. The salinity distributions are shown for the surface and for 40 feet. The pattern of coastal circulation is referred to the cyclonic eddy off the Florida west coast. Two major indrafts of high salinity water toward the shoreline are found. The mechanics of this phenomenon, and also the permanency of the observed pattern are discussed."

HELA, ILMO, DONALD DE SYLVA, and CLARENCE A. CARPENTER. 1955. Drift currents in the red tide area of the easternmost region of the Gulf of Mexico. *Marine Laboratory, University of Miami.* Pp. 1-31. (Mimeographed)

"ABSTRACT. During 1954 two driftcard operations were performed in the easternmost shallow region of the Gulf of Mexico. Given the locations and times of the drops and of their recovery, the direction and speed of the resultant movement of the driftcards may be deduced with relative accuracy, provided that one takes into consideration only those cards which are found either afloat offshore or those which, if picked up ashore, are found soon after their landing.

"These operations were performed as a part of the Red Tide studies for the Florida State Board of Conservation . . ."

HOWELL, JOHN F. 1953. *Gonyaulax monilata* sp. nov., the causative dinoflagellate of a red tide on the east coast of Florida in August-September, 1951. *Trans. Amer. Micr. Soc., 72*(2): 153-156.

This species was reported from the Indian and Banana Rivers, Florida, and from City Pier, Sarasota, Florida. An additional note states that a chain-forming dinoflagellate, with the plates identical to those of *Gonyaulax monilata*, occurred in a sample from Offatts Bayou, Texas.

INGERSOLL, ERNEST. 1882. On the fish-mortality in the Gulf of Mexico. *Proc. U. S. Nat. Mus., 4:* 74-80.

An investigation into the so-called "poisoned water" problem. According to this author, mortality occurred in 1844 when there was "widespread destruction of all sorts of salt-water animal life . . ."

p. 75. "Again, in 1854 the fishes suffered all along the southern shore, and have done so at intervals since to a less degree, until in 1878 an excessive fatality spread among them, which was wider in the extent of its damaging effects and probably more destructive in point of number of victims than the latter visitation of 1880. Even the cooler half of 1879 was not exempt from some appearance of the plague."

p. 75-76. "Concerning the attack of 1880 I am able to say more. It began suddenly, and immediately followed the terrible hurricane which is known as the 'August gale', the fish and all other ocean life suddenly dying in hordes all along the southern (eastern) shore of Tampa Bay, on Egmont Key, at its mouth, which was the most northern point, and thence southward as far as Shark River, in Whitewater Bay, on the coast."

p. 78. "In the pure element, between the deadly streaks, fish were as abundant as ever at the distance from the coast where the smacks operated, and their wells were often filled with promptness; but it was found that it was impossible, even by going straight out to the Tortugas, to run the gauntlet of the poisoned water floating between there and Cape Sable, since if once it was encountered, and entered the well, a very few minutes sufficed to bring about the death of every fin of the cargo. I have a few notes, culled from the Key West journals, which show that a loss of nearly $10,000 resulted from only four or five such misfortunes. The consequence was that for some weeks the

fishing throughout all that part of the Gulf had to be wholly abandoned, involving the idleness of a large number of vessels and their crews."

p. 79. "It was the death of sponges, conchs, sea-anemones, crawling horseshoe-crabs, of toad-fish, skates, and the like, which keep close down on the bottom, that first apprised the fishermen of the presence of their dreaded and mysterious enemy."

INGLE, ROBERT M. 1954. Irritant gases associated with red tide. *Marine Laboratory, University of Miami,* Spec. Serv. Bull. No. 9: 1-4.

"SUMMARY. 1. Irritant effects to the nose and throat associated with red tides are temporary. No after-effects have been reported.

"2. Irritant effects are present only when red tide occurs and even then do not appear unless wind-driven waves with associated water vapor and droplets exist. Naturally, on some occasions, droplets will remain in suspension in the air for a short time after the wind that created them has subsided.

"3. Because irritant exists probably either as particles or droplets carried by wind then thrown into the air by spray, it does not usually go far inland beyond open beaches.

"4. There is no evidence that the irritating effects are caused by a military gas or any other man-made product."

INGLE, ROBERT M., and DONALD P. DE SYLVA. 1955. The red tide. *Marine Laboratory, University of Miami,* Ed. Ser. 1: 1-30.

"SUMMARY. 1. The Florida Red Tide is caused by microscopic organisms. Normally present in sea water along the lower Florida west coast in small numbers, they may suddenly reproduce to form many billions of individuals. The water is characteristically discolored. At certain times these organisms become numerous enough to kill many thousands of marine animals.

"2. Since 1844 the Florida Red Tide has occurred at least 13 times in major proportions. There are apparently gaps of as much as fourteen years when no Red Tides have been reported.

"3. When the Red Tide appears, a slightly irritating gas may be noticed. No evidence exists that this gas is due to a dumping of scrap war-material, or other man-made products, into the coastal waters. Much scientific evidence links the gas with the Red Tide organism. The effects of the gas are restricted to the sea or beach areas and are temporary. The slight coughing sensations disappear when the Red Tide diminishes.

"4. Fish not killed or whose behavior is not noticeably affected by Red Tide are apparently safe for human consumption, according to all available information.

"5. The riddle of the Red Tide has been under continuous study by a team of trained marine scientists of the Marine Laboratory of the University of Miami since 1947. The U. S. Fish and Wildlife Service is also engaged in this study. Individuals from the University of Florida, the University of Tampa, and other organizations, have also worked on this problem at various times.

"6. Several theories have been proposed to explain the biological mechanisms that start and maintain Red Tides. Presently, most of these are being investigated. Full-scale, continued research is needed to solve a problem as complicated as Red Tide.

"7. Red Tides which have occurred in other parts of the world since Biblical times were usually associated with some type of water-borne enrichment or fertilization. The high phosphorus content of the soils and offshore bottom of Florida's west coast offers a likely avenue of study, especially since such streams as the Peace River are shown to carry substantial amounts of phosphorus to the Gulf."

JEFFERSON, J. P. 1879. On the mortality of fishes in the Gulf of Mexico in 1878. *Proc. U. S. Nat. Mus., 1*: 363-364.

This publication consists of a letter from J. P. Jefferson, Lieutenant Fifth Regiment Artillery, to Prof. Spencer F. Baird, Smithsonian Institution, Washington, D. C. The letter was written in December, 1878, and describes 'discolored water' moving down along the coast, across Florida Bay, to Tortugas (about November 20) and extending to at least as far as Key West. Dead fish were reported from Fort Jefferson and neighboring keys, the north side of the island of Key West, and about 15 miles out in the Gulf Stream. In Tampa Bay oysters were killed. It was reported that the Caloosahatchee River overflowed its banks in October and the whole country side was flooded.

JEFFERSON, J. P., JOSEPH Y. PORTER, and THOMAS MOORE. 1879. On the destruction of fish in the vicinity of the Tortugas during the months of September and October, 1878. *Proc. U. S. Nat. Mus., 1:* 244-246.

A report, in the form of three letters, of fish dying and conchs being killed by "dark cypress looking water" in the Gulf of Mexico, especially in Florida Bay.

KETCHUM, BOSTWICK H., and JEAN KEEN. 1948. Unusual phosphorus concentrations in the Florida "red tide" sea water. *J. Mar. Res.*, 7(1): 17-21.

"SUMMARY. 1. The total phosphorus content of waters containing dense *Gymnodinium* populations was found to be 2½ to 10 times the maximum to be expected in the sea. The possibility that upwelling of nutrient-rich, deep water is the explanation of this intense plankton bloom is thereby excluded.

"2. It is suggested that future studies of intense plankton blooms include total phosphorus determinations at various depths. The results would differentiate between terrigenous contaminations and swarming of the organisms at the sea surface."

KIERSTEAD, HENRY, and L. BASIL SLOBODKIN. 1953. The size of water masses containing plankton blooms. *J. Mar. Res., 12*(1):141-147.

"ABSTRACT. If a phytoplankton population is assumed to be increasing logarithmically in a mass of water surrounded by water which is unsuitable for the survival of the population, it can be shown that there is a minimum critical size for the water mass below which no increase in concentration of phytoplankton can occur. In a one-dimensional water mass with leakage at both ends, this size, after a time of the order of $L^2/8\ ^2D$, is given by

$$L_c = \sqrt{\frac{D}{K}},$$

where L_c is the length of the water mass, D the diffusion, and K the rate or increase of the population. The corresponding size in a cylindrical water mass is given by

$$R_c = 2.4048$$

where R_c is the radius of the water mass."

KING, GLADYS S. 1950. Production of red tide in the laboratory. *Proc. Gulf and Caribbean Fish. Inst.* (Second Ann. Session): 107-109.

An experimental investigation of the nutritional requirements of a protozon, *Plagicampa marina*, and the dinoflagellate, *Gymnodinium simplex*. This work indicates that the two organisms studied not only are able to utilize certain organic nitrogenous material when disolved in ocean water, but that actually such substances are required in the organisms

nutrition. The work is offered as "a basis for recommending an investigation of dissolved organic nitrogenous matter in Gulf water as a clue to outbursts of Red Tide dinoflagellates."

KING, JOSEPH E. 1949. A preliminary report on the plankton of the west coast of Florida. *Quart. J. Fla. Acad. Sci., 12(2):* 109-137.

In general the purpose of this paper is to identify the planktonic forms, especially the dinoflagellates and copepods, in the waters off the west coast of Florida. There is a brief discussion of red tide and one of the main objectives of the paper is to determine "the normal or typical plankton" which was present during the investigation period of about ten months (January to October, 1949). *Gonyaulax triacantha, Gonyaulax* sp., *Polykrikos* sp. *(schwartzi ?), Cochlodinium* sp. *(virescens ?), Gymnodinium* sp. *(nelsoni ?), Ceratium furca,* and *Dinophysis* sp. were among the dinoflagellates found in a surface sample of "red water".

LACKEY, JAMES B. 1956. Note on the occurrence of *Gymnodinium brevis* in Trinidad waters. *Quart. J. Fla. Acad. Sci., (in press).*

The recorded geographical range of *G. brevis* is extended to the coast of Trinidad.

LACKEY, JAMES B., and JACQUELINE A. HYNES. 1955. The Florida Gulf coast red tide. *Engineering Progress at the University of Florida,* 9(2): 3-23.

"FORWARD. The work detailed in this bulletin represents an attempt to evaluate the effects of *Gymnodinium brevis,* its behavior and its distribution; some investigation of factors which may cause its phenomenal growth and of factors which may help in its control. Our laboratory has not attempted to investigate phases of the problem which are under attack at the University of Miami or at the laboratory of the U. S. Fish and Wildlife Service . . ."

LaCOSSITT, HENRY. 1954. The truth about Florida's red tide. *Sat. Eve. Post, 227*(7): 28-29, 67-68.

A popular account of the red tide. The author visited Bradenton where he experienced irritations of the nose and throat from the so-called "gas".

LASKER, REUBIN and F. G. WALTON SMITH. 1954. Red tide. In "Gulf of Mexico. Its origin, waters, and marine life." *Fish. Bull., U. S. Fish Wild. Serv., 55*(89): 173-176.

A review of Florida's red tide.

LONG, E. JOHN. 1953. The red tide hits and runs. *Nature Mag., 46*(3): 125-128 and 162.

Florida's red tide problem reviewed in a popular article.

MARINE LABORATORY, UNIVERSITY OF MIAMI. 1948. The red tide. *State of Florida, Board of Conservation,* Educ. Ser. No. 1: 1-14.

An educational bulletin on the red tide.

MARINE LABORATORY, UNIVERSITY OF MIAMI. 1948. Report on a survey of the sponge grounds north of Anclote Light. *Florida State Board of Conservation* (January). Pp. 1-6. (Mimeographed)

From "SUMMARY". pp. 1-2. "3. The enormous depletion of the sponge grounds is due to several factors. A lack of proper scientific management and control brought about a slow but continuous drop in production since 1935. The fungus disease of 1939 caused a very considerable mortality which was aggravated by failure to institute

proper control. During 1946 and 1947 a second mortality due to natural causes brought further losses. At the present time no active disease is present in the area north of Anclote Light, and the greater part of the grounds are in a very healthy condition. No sponges were present in the deep water grounds and no new varieties of sponge which could become of commercial value were found."

MARINE LABORATORY, UNIVERSITY OF MIAMI. 1949. Quarterly report on fisheries research. Florida State Board of Conservation (December). Pp. 1-3. (Mimeographed)

p. 2. "Red Tide . . . Certain organisms closely related to the Red Tide dinoflagellate have been successfully cultured in sea water supplemented by yeast extract. Organisms have been in continuous culture in this nutrient for nearly a year, with no sign of diminishing vitality. " . . . "

MARINE LABORATORY, UNIVERSITY OF MIAMI. 1949. Biennial report on the marine fishery research program. *Florida State Board of Conservation* (June). Pp. 1-9. (Mimeographed)

p. 4. "Investigations of the Red Tide were begun during 1947 in behalf of the Board of Conservation, and the microscopic organism responsible for it has been described in reports issued by the Mairne Laboratory since that date. . .

"The research has been continued since October 1948 and numerous chemical samples of the seawater in the Gulf of Mexico have been collected during the sponge surveys. These have been analyzed by oceanographic chemists in an attempt to study the fundamental conditions existing in the Gulf water. A knowledge of this gives some indication of the possible causes of the abnormal chemical conditions which existed in 1948 and were responsible for the growth of Red Tide organism. " . . . "

MARINE LABORATORY, UNIVERSITY OF MIAMI. 1950. Quarterly report on fisheries research. *Florida State Board of Conservation* (October). Pp. 1-7. (Mimeographed)

From "SUMMARY". p. 2. "Productivity and nutrition studies on plankton and a study of the underlying physical and chemical conditions have been carried out as part of a long term program and includes the red tide studies begun in 1947."

MARINE LABORATORY, UNIVERSITY OF MIAMI. 1952. Quarterly report on fisheries research. *Florida State Board of Conservation* (December). Pp. 1-10. (Mimeographed)

From "SUMMARY". p. 2. "7. When the recent outbreak of 'red tide' was reported, a team of biologists and hydrographers proceeded to the area. A vessel was chartered, with the assistance of the Gulf Oil Company. Guided by air observation, a series of sections were made across the affected areas. The outbreak was found to be caused by the same organism *(Gymnodinium brevis)* that caused the serious 'red tide' of 1947. A living culture of this organism is on hand at the Laboratory. Results of the observations are being studied to correlate hydrographic conditions with the outbreak."

MARINE LABORATORY, UNIVERSITY OF MIAMI. 1953. Quarterly report on fisheries research. *Florida State Board of Conservation* (December). Pp. 1-6. (Mimeographed)

p. 5. "A serious outbreak of Red Tide occurred during the final quarter of 1953. Several biologists of the Laboratory went to the area during the emergency."

MARINE LABORATORY, UNIVERSITY OF MIAMI. 1954. Quarterly report on fisheries research. *Florida State Board of Conservation* (March). Pp. 1-11. (Mimeographed)

A statistical correlation showed a relationship between Red Tide outbreaks and rainfall plus ground water level.

MARINE LABORATORY, UNIVERSITY OF MIAMI. 1954. Emergency report on the Florida red tide. *Florida State Board of Conservation* (January). Pp. 1-4. (Mimeographed)

This report consists of (a) summary of research results, and (b) recommendations.

MARINE LABORATORY, UNIVERSITY OF MIAMI. 1954. Red tide studies (Preliminary report, January to June 1954). *Florida State Board of Conservation* (August). Pp. 1-117. (Mimeographed)

"SUMMARY". ". . .

". . .

"3. The Red Tide fish kill was shown in 1947 to be of the nature of a plankton bloom in which the dinoflagellate, *Gymnodinium brevis,* highly poisonous to fishes, is predominant. The present inquiry was directed to a concentrated study on *HOW* the outbreaks originate and *WHEN* to expect them. Because of the limited period (5 months) available it was believed this approach would be most productive. Incidental data has nevertheless accrued, which gives a clearer picture of the nature of Red Tide. Some speculation is also offered as to control measures.

"4. In the course of the work a survey was made of the scientific literature concerning plankton blooms throughout the world.

"5. Statistical methods were applied to determine empirically what meteorological and other ambient phenomena exhibited a significant correlation with Red Tide. The initial series of fish kills constituting a Red Tide cycle were found to occur most frequently in the month of October and within the dates of the new moon plus or minus three days.

"A cycle or series of outbreaks is most likely to occur when the annual rainfall of the Peace River drainage area is above the fifty year average. A correlation also exists between outbreaks and a high maximum annual discharge of the Peace River. The 12 month running average of Peace River area rainfall seems best for forecasting outbreaks. No correlation has so far been satisfactorily established with wind conditions, or with the height of the water table, but this work is being continued. The salinity of gulf water near shore is lower in Red Tide years. There has been no relation found between Red Tide and the production of pebble phosphate in the Peace River drainage area.

"6. The results of hydrographic studies carried out in previous years had demonstrated the presence of Red Tide at the interface between Gulf and Bay waters. Attempts were made to develop further these relationships, but no evidence was found to substantiate the idea of a more or less continuous front between Gulf and Bay waters along which the Red Tide progresses. It now seems far more probable that a periodic separation of masses of Bay water susceptible to Red Tide takes place at the mouth of the passes and that these masses move with prevailing currents, usually northward, slowly losing their identity by mixing and diffusion with the Gulf water.

"7. Evidence suggests that the initial fish kills are most active and that *G. brevis* blooms most often originate at the inner side of such passes as Boca Grande; and that the disturbance may then travel with currents while still active, mainly in a northward direction.

"8. Evidence tends to show that nutrient inorganic phosphorus content of the water decreases in its passages from the Peace River to the

passes and that organic phosphorus increases. The total phosphorus however, decreases, suggesting that a precipitation or sedimentation takes place at the passes. The Peace River is the main source of phosphorus, the Manatee River somewhat less and the Caloosahatchee least.

"9. Evidence is offered that Red Tide may possibly involve more than one toxic bloom organism and it is therefore considered possible that greater progress may be made in future research by concentrating on the nature of the mechanism that gives rise to these blooms rather than by studying the particular organisms which are characteristic of its climax.

"10. A study of commercial fish landings fails to reveal any significant decrease in the commercial catch in relation to Red Tide. This is being given more detailed study.

"11. A tentative working hypothesis of the origin and nature of Red Tide outbreaks is offered as a basis for further investigations.

"12. It is strongly recommended that advance planning be undertaken for the control of Red Tide should outbreaks occur in the fall of this or future years. The most practical method of alleviating the damage is considered to be by seining of dead fish while concentrated in the passes and at sea, before drifting on the beaches.

"It is considered that chemical control is more expensive and less likely to be successful than the control of dead fish by seining. Nevertheless, it is recommended that chemical treatment be applied at the passes at the earliest possible moment of a Red Tide outbreak in order to evaluate its usefulness.

"13. Since Red Tide conditions, once they appear outside of the Keys are probably self perpetuating to a considerable extent and thus difficult to control, it is suggested that attention be paid to the possibility of modifying the nutrient conditions of the Bay waters in such a way as to prevent Red Tide conditions from developing. A large scale fish culture program in the Bays, with the addition possibly of supplementary nutrients other than phosphorus might conceivably be brought about. Under these conditions the nutrient regime and the food chains might conceivably be changed so as to minimize the development of conditions suitable to Red Tide."

MARVIN, KENNETH T. 1955. Oceanographic observations in west coast Florida waters, 1949-1952. *Spec. Sci. Rep. U. S. Fish Wildl. Serv.*, (149): 1-32.

Chemical, meteorological, and hydrographic data from work done along the west coast of Florida between 1949 and 1952 are presented.

MOORE, H. F. 1910. The commercial sponges and the sponge fisheries. *Bull. U. S. Bur. Fish., 26*(1): 399-512.

So-called "poison water" is reported as being responsible for the almost complete extermination of sponges from large areas. This phenomenon is said to recur at irregular intervals of about ten years. It is reported to have happened in 1878 between Johns Pass and Cedar Keys and in about 1895 from St. Marks to the mouth of the Suwannee River.

MOORE, M. A. 1882. Fish mortality in the Gulf of Mexico. *Proc. U. S. Nat. Mus. 4:* 125-126.

This is the publication of a letter originally written during November, 1880, by M. A. Moore to Professor Baird, Commissoner of Fish and Fisheries, Washington, D. C. He reports the cause of the mortalities of about 1878 and 1880 to be poisoned water and claims these waters seem to be centered more around the mouth of Charlotte Harbor and off Punta Rassa than elsewhere. The poisoned water seemed to affect

the bottom fish more than others. It is the opinion of this writer that volcanic action is the underlying cause of the phenomenon.

MURDOCK, JAMES F. 1954. A preliminary survey of the effects of releasing water from Lake Okeechobee through the St. Lucie and Caloosahatchee estuaries. *Marine Laboratory, University of Miami* (Report to Corps of Engineers, U. S. Army). Pp. 1-89. (Mimeographed)

pp. 47-48. "The phenomena causing the most damage to west coast interests during the past few years has been the 'Red Tide'. At present a study is being made by this laboratory of the factors which might operate to bring about a 'Red Tide'. It is suspected that these factors would be more likely to be found originating from inshore than from offshore waters. The alteration of the natural drainage features of south and central Florida by the work carried on by the U. S. Army Engineers is one of the factors being investigated. The data collected and analyzed to date does not eliminate the possibility that a continuing high rate of water release may be a contributory cause of Red Tide outbreaks. On the other hand, since Red Tide outbreaks show a general correlation with the cumulative monthly rainfall of the peninsula, it is probable that the contributions of the Peace River and other drainage systems are sufficiently greater that a reduction of flow in the Caloosahatchee River would have little effect upon the probability of a Red Tide outbreak."

NICHOLSON, C. A. 1954. Blood in the Gulf. *Field & Stream* (August). Pp. 46-48, and 106-108.

A popular account of the red tide in Florida's waters.

ODUM, HOWARD T. 1953. Dissolved phosphorus in Florida waters. *Florida Geol. Survey,* Rept. No. 9, Misc. Studies, Part 1: 1-40.

"ABSTRACT. A basic survey has been made of the concentrations of dissolved phosphorus in many types of Florida's surface waters. The extensive deposits of phosphate rock in Florida lead to unusually high dissolved phosphorus contents in the streams and lakes whch drain these areas. Thus these waters are potentially of high fertility for growth of aquatic organisms. Additional quantities of dissolved phosphorus are being added by sewage and industry in some areas, although little recognition has been made of the possibly large biological effects that relatively small amounts of added phosphorus can have on those areas which are not receiving drainage from phosphate areas. The moderately low phosphorus content of basic springs in contrast to acid surface streams suggests a controlling role of pH in phosphorus solubility in Florida. It seems likely that percolating rainwaters are continually concentrating phosphorus in the layers just beneath the surface as the acid rainwater becomes basic. The natural and artifical phosphates contributed to Florida's surface streams hypothetically seem to be of the magnitude to contribute to red tide phenomena and the rapid growth of water hyacinths in prescribed areas."

ODUM, HOWARD T., J. B. LACKEY, JACQUELINE HYNES, and NELSON MARSHALL. 1955. Some Red Tide characteristics during 1952-1954. *Bull. Mar. Sci. Gulf and Caribbean,* 5(4): 247-258.

"ABSTRACT. Survey counts of *Gymnodinium brevis,* miscellaneous chemical analyses (Kjeldahl nitrogen, total phosphorus, total organic matter, chlorophyll, and nitrate), and a few light itensity and productivity measurements in Florida's red tide zone from 1952 to 1954 indicated a widespread general regime of this dinoflagellate growing sparsely in heterogeneous poor to moderately fertile water with a high N/P ratio. Occasional bloom patches and fish kills were accompanied by somewhat higher nutrient levels. The fertile estuaries, Tampa Bay and Charlotte

Harbor, in contrast to the Caloosahatchee River are capable of stimulating coastal fertility with injections of nitrogen and phosphorus. Offshore mixing of high N/P ratio water of the Caloosahatchee estuary and the low N/P ratio water of Tampa Bay and Charlotte Harbor may produce a wide range of nutrient conditions. A decrease in estuarine pollution is suggested as a remedial experiment."

PHILLIPS, CRAIG, and WINFIELD H. BRADY. 1953. Sea pests. *Marine Laboratory, University of Miami.* Pp. 1-78.

The red tide phenomenon is discussed briefly in this booklet.

PIERCE, H. D. 1883. 53—The spawning of bluefish—an opinion of the cause of mortaliy of fish in the Gulf of Mexico. *Bull. U. S. Fish Comm.*, 3:332. (From a letter to Prof. S. F. Baird)

This author does not believe "fish kills" to be the result of poisonous waters. He attributes the mortalities to lowered water temperatures.

PIERCE, H. D. 1884. 142—Notes on the bluefish, mortality of Florida fishes, etc. *Bull. U. S. Fish Comm., 4*(17): 263-266.

This work is a continuation of that by PIERCE (1883). The suggestion is made that cold water possibly caused the 1880 epidemic on the Florida west coast.

PORTER, JOSEPH Y. 1882. On the destruction of fish by poisonous water in the Gulf of Mexico. *Proc. U. S. Nat. Mus., 4:* 121-123.

Included in this article is a letter by J. Y. Porter to Prof. Spencer F. Baird, Washington, D. C. In the letter one opinion as to the cause of the destruction of fish was that it was because of "the saturated condition of the water with dogwood *(Cornus Florida)*" and another theory was that volcanic eruption caused the mortality. Also in this work is a letter written by C. J. Kenworthy to the editor of "Forest and Stream" and a reply to this letter is also included. Kenworthy reports that the fish mortality problem demands investigation and suggests that a government dispatch boat located at Key West be used. This suggestion was seconded by the editor of "Forest and Stream". The editor states that his organization had already suggested the use of fluorescine to determine the origin of a boiling spring off the Gulf coast.

RATHBUN, RICHARD. 1887. The sponge fishery and trade. *U. S. Comm. Fish and Fisheries* (The Fisheries and Fish. Indust. U. S.), Sect. V, 2(23): 817-841.

"Poisoned waters" are reported and Ingersoll (1882) is quoted.

SATER, EDNA N. 1954. Florida's red tide problem. *Fish. Leafl. Wash.*, 420: 1-11.

"SUMMARY. Progress on Florida's red-tide problem since the 1946-47 outbreak can be summarized as follows:

"1. 'Red tides', noted for their discolored water, are caused by a tiny marine organism so small that it cannot be seen by the naked eye. *Gymnodinium brevis* is the scientific name of this fish-killing plague which also produces a 'gas' irritating to nostrils and throats of people.

"2. Rainfall, marsh drainage, salinity, wind, and temperature—in certain combinations—provide the physical conditions in which the red-tide organisms can get started. These organisms multiply rapidly and derive nutrients from the fish that are killed as well as from land drainage.

"3. Red-tide organisms are now being grown artificially in the laboratory, thus permitting the testing of different chemical compounds as control agents. Copper sulfate is the most promising to date.

"4. Federal and State research is coordinated and citizens' groups are organized to report the detection of new outbreaks and to assist in control measures in an emergency."

SHALER, N. S. 1890. The topography of Florida. With a note by Alexander Agassiz. *Bull. Mus. Comp. Zool. Harv., 16*(7): 139-158.

See AGASSIZ (1890).

SLOBODKIN, L. BASIL. 1953. A possible initial condition for red tides on the coast of Florida. *J. Mar. Res., 12*(1): 148-155.

"ABSTRACT. It seems likely that the occurrence of a discrete mass of water, with a salinity lower than that of normal Gulf of Mexico surface water, is a necessary prerequisite for the occurrence of red tide off the Florida Coast."

SMITH, F. G. WALTON. 1948. (1949). Probable fundamental causes of red tide off the west coast of Florida. *Quart. J. Fla. Acad. Sci., 11*(1): 1-6.

A discussion of the factors which evidently could reasonably account for red tide along the west coast of Florida. It is suggested that inorganic phosphorus may be the limiting factor of plankton growth in these waters at all times.

SMITH, HUGH M. 1898. The Florida commercial sponges. *Bull. U. S. Fish Comm., 17:* 225-240.

"Black" or "poisonous water" is reported and Ingersoll (1882) is quoted.

TAYLOR, HARDEN F. 1917. Mortality of fishes on the west coast of Florida. *Rep. U. S. Comm. Fish,* (Doc. No. 848. Issued June 13, 1917): 24 pp.

"Poison water" is reported to have periodically killed large numbers of fishes and other animals along the Florida west coast during the 75 years preceding 1916. The critical area for these "kills" was from Key West north to near Cedar Keys and the "kills" were reported for the years 1844, 1854, 1878, 1880, 1908, and 1916. The 1916 outbreak. which appeared progressively southward from Boca Grande to Marco, is discussed and the meteorological conditions are reported. It was stated that in November, 1916, two people in Fort Myers died from eating fish killed by this phenomenon. The species of fish killed are listed; a number of invertebrates, sea urchins *(Arbacia),* the horseshoe crab *(Limulus),* and sponges, were also noted. Barnacles, oysters, mussels, conchs, hermit crabs, and porpoises did not appear to be harmed. A discussion of the possible causes of this mortality include:

"(1) water from the Everglades charged with tannin and products of decomposition of palmettoes and mangroves; (2) extraordinary abundance of *Peridinium* known to have occasioned the death of fishes in different parts of the world; (3) a disease, fungoid, parasitic, or bacterial; (4) dilution of the water by unusually heavy rains; (5) an issue of gas, volcanic or natural; and (6) earthquakes or seaquakes."

According to the author, the sixth cause appears to have the most promising possibility.

UNITED STATES FISH AND WILDLIFE SERVICE. 1954. Red tide research. Issued in form of a newsletter (September). Pp. 1-4. (Mimeographed)

Experimental work on the control of red tide organisms by the use of copper sulphate is mentoned.

WALKER, S. T. 1884. Fish mortality in the Gulf of Mexico. *Proc. U. S. Nat. Mus., 6*(6): 105-109.

A discussion of a fish mortality during October, November and December of 1880. The statements of a number of local residents are included: This author's observations summarized are (p. 106):

"1. The dead fish were most numerous on the outside beaches and on the inside beaches of the outer line of keys.

"2. That dead fish were least numerous about the mouths of creeks and rivers, decreasing gradually as one approached such places.

"3. That the poisoned water was not diffused generally, but ran in streams of various sizes, as proven by fish dying in vast numbers instantly upon reaching such localities.

"4. That the fish were killed by a specific poison, as proven by the sickness and death of birds which ate the dead fish.

"5. The fish began dying on the outside beaches first, as Mr. Strand, assistant light-keeper at Egmont, reports them coming up first on the 17th of October, while Mrs. Hoy observed them first on the 1st or 2nd of November, at Little Manatee River.

"6. The examination of many hundred recently-dead fish revealed no signs of disease. The colors were bright, the flesh firm, and the gills rosy. The stomach and intestines appeared healthy."

WEBB, JOHN G. 1887. 5.- The mortality of fish in the Gulf of Mexico. *Bull. U. S. Fish Comm., 6:* 11-13.

This writer believes the fish mortality to be caused "by noxious and poisonous gases which permeate portions of the Gulf and its bays, and which are derived from underground streams of water that flow into the sea." (p. 11)

WILSON, WILLIAM B., and ALBERT COLLIER. 1955. Preliminary notes on the culturing of *Gymnodinium brevis* Davis. *Science, 121* (3142): 394-395.

"Table I. Medium for the unialgal isolation of *G. brevis* Davis. After all additions are made, there is approximately 110 ml of medium.

Aged sea water (salinity, about 36.5 ppt)	95.0	ml
Distilled water*	5.0	ml
NH_4Cl**	0.1	mg
KH_2PO_4**	0.05	mg
$MgCl_26H_2O$**	0.02	mg
$NaHCO_3$**	0.1	mg
$Na_2S.9H_2O$**	0.1	mg
Vitamin B_{12}	0.1	ug
Thiamine hydrochloride	1.0	mg
Biotin	0.05	ug
Soil extract†	2.0	ml
EDTA.Na (6 ml of 0.25-percent solution)	15.0	mg

* More or less may be required, depending on the salinity.

** Added as 0.5 ml of the following solution of the components of Van Niel's medium for sulfur bacteria: NH_4Cl, 0.2 g; KH_2PO_4, 0.1 g; $MgCl_2.6H_2O$, 0.04 g; $NaHCO_3$, 0.1 g; and $Na_2S.9H_2O$, 0.2 g to 1 lit of distilled water.

† Simmer for 40 min. a mixture of 500 g of garden soil and 1 lit of distilled water. Let it stand for 4 days and decant the supernatant. Repeat simmering and decantation until extract is clear. Our soil gives a yellowish-brown extract."

WITWER, STAN. 1954. Can science stop the deadly red tide? *The Atlanta Journal and Constitution Magazine* (8-15-54). Pp. 28-29.

A popular account of Florida's red tide.

WOODCOCK, ALFRED H. 1948. Note concerning human respiratory irritation associated with high concentrations of plankton and mass mortality of marine organisms. *J. Mar. Res.*, 7(1): 56-62.

"SUMMARY. 1. Nose and throat irritations, similar to those naturally occurring in the Venice Beach region of the Gulf coast of Florida during July 1947, can be produced by breathing air artificially laden with small drops of the Gulf of Mexico water which contains (or contained) 56 x 10^6 dinoflagellates per liter.

"2. The presence of naturally produced drops of sea water in the air along Venice Beach, Florida, during a time when respiratory irritation occurred, is indicated. Approximate drop size range and concentration is given.

"3. Simple experiments show that respiratory irritation is always associated with the presence of small drops of 'red water' in the air.

"4. 'Red water' stored without preservative for several weeks retained its irritating qualities apparently undiminished. The persistence of the irritant through weeks of storage without preservative and through large temperature changes indicates a rather stable substance.

"5. Drops from effervescing heated 'red water' were more irritating than drops from effervescing water at room temperature, and these later drops seemed more irritating than spray drops produced by the hand atomizer.

"6. The irritant passed through a fine bacterial filter (1 to 1.5 mircon openings).

"7. When air-borne, the irritant can be so reduced in concentration, by inhaling through absorbent cotton, that it ceases to affect the respiratory system."

ADDENDUM

FEINSTEIN, ANITA. 1956. Correlations of various ambient phenomena with red tide outbreaks on the Florida west coast. *Bull. Mar. Sci. Gulf and Caribbean*, *6*(3): 209-232.

"ABSTRACT. Investigations have been made to determine whether any simple, linear correlations exist between Red Tide outbreaks and various ambient phenomena. Outbreaks are compared with rainfall, tropical disturbances, and river runoff. A pattern of cyclic recurrence of outbreaks is presented. An attempt is made to show the path of individual outbreaks."